Palaeogeography, Palaeoclimatology, Palaeoecology 520 (2019) 173–180

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Synchronous onset of the Mid-Carnian Pluvial Episode in the East and West Tethys: Conodont evidence from Hanwang, Sichuan, South China

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ARTICLE INFO

Keywords:
Late Triassic
Biostratigraphy
Climate change
Mazzaella carnica

ABSTRACT

The Mid-Carnian Pluvial Episode (or "Carnian Wet Intermezzo") interrupted the generally arid climate of the Triassic in different regions. An enhanced high-resolution time scale, especially with intercalibrated ammonoid, conodont and magnetic polarity zones, is required to understand the global coincidence of regional manifestations of this climatic change and possible causation factors. The termination of oolite-rich limestones and the initial influx of terrigenous debris at the Unit 1 to Unit 2 boundary in the Guanyinya and Qingyangou sections from Hanwang of the Sichuan Province, South China, are interpreted as a local shift from arid to humid climate. A detailed conodont sampling assigns this facies change to within the *Mazzaella carnica* range zone of the late Julian substage. Therefore, the conodont markers imply it is coeval with the onset of the mid-Carnian " Rheingraben Event" at the Rappoltstein reference section in southern Germany; and ammonoids in that section enable correlation to the beginning of a negative carbon-isotope excursion that coincides with the termination of the Yangtze Platform at the Longchang reference section in Guizhou, South China. The first occurrence of *Parapetella*? *guanyinensis* sp. nov. is very close to the onset of the interpreted Carnian Pluvial Episode at Hanwang and to the cessation of widespread shallow-water carbonate facies in South China. In contrast to this "Intermezzo" episode in the West Tethys region, arid conditions did not resume in South China in the Eastern Tethys until long after the termination of this wet climate in late Julian.

1. Introduction

The Mid-Carnian Pluvial Episode is an anomalous global event during the general arid climate regime of the Triassic Period. This "most distinctive climate change within the Triassic" (Preto et al., 2010) was followed by 'the earliest record of significant dinosaurs on land and the emergence of the calcareous nannoplankton in the oceans' (e.g., reviews in Ogg, 2015). This humid episode has received different names in the literature, including "Wet Intermezzo" (Kozur and Bachmann, 2010), Rheingraben Turnover (Schlager and Schöllnberger, 1974), Carnian Pluvial Episode or CPE (Simms and Ruffell, 1989; Rigo et al., 2007), Carnian Pluvial Event or CPE (Roghi, 2004; Rigo et al., 2007; Dal Corso et al., 2015), Carnian Crisis (Hornung et al., 2007a), Carnian Humid Episodes or CHE (Ruffell et al., 2015; Mueller et al., 2016; Sun et al., 2016), and Carnian Black Shale Event (Hornung and Brandner, 2005; Shi et al., 2009). An international workshop during 2017 on this interval recommended "Carnian Pluvial Episode" (Dal Corso et al., 2018), and this terminology is followed here.

Possible contributing factors to this Carnian Pluvial Episode are an eruption of the enormous Wrangellia Large Igneous Province (e.g. Furin et al., 2006; Dal Corso et al., 2012, 2015; Mueller et al., 2016; Sun et al., 2016), a change in the pattern of the Pangean "mega-monsoons" (Hornung and Brandner, 2005; Preto et al., 2010; Kozur and Bachmann, 2010) or both (Simms and Ruffell, 1989; Shi et al., 2010). However, to prove whether the regional excursions during the Carnian are coeval and to test any cause-effect hypothesis, it is necessary to have precise global correlations. Developing and applying a detailed Carnian biostratigraphy to regional records is one essential tool, but it is a challenge to correlate among different regions and facies.

The onset of the Carnian Pluvial Episode is reported to be just before the *Austrotrachyceras austriacum* ammonoid zone near the end of Julian 1 substage of the western Tethys region (Fig. 1), but the intercalibration of ammonoid, conodont and other regional biozones for the Carnian Stage is a topic of active research and debate.

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https://doi.org/10.1016/j.palaeo.2019.02.004
Received 16 April 2018; Received in revised form 5 February 2019; Accepted 5 February 2019
Available online 08 February 2019
0031-0182/

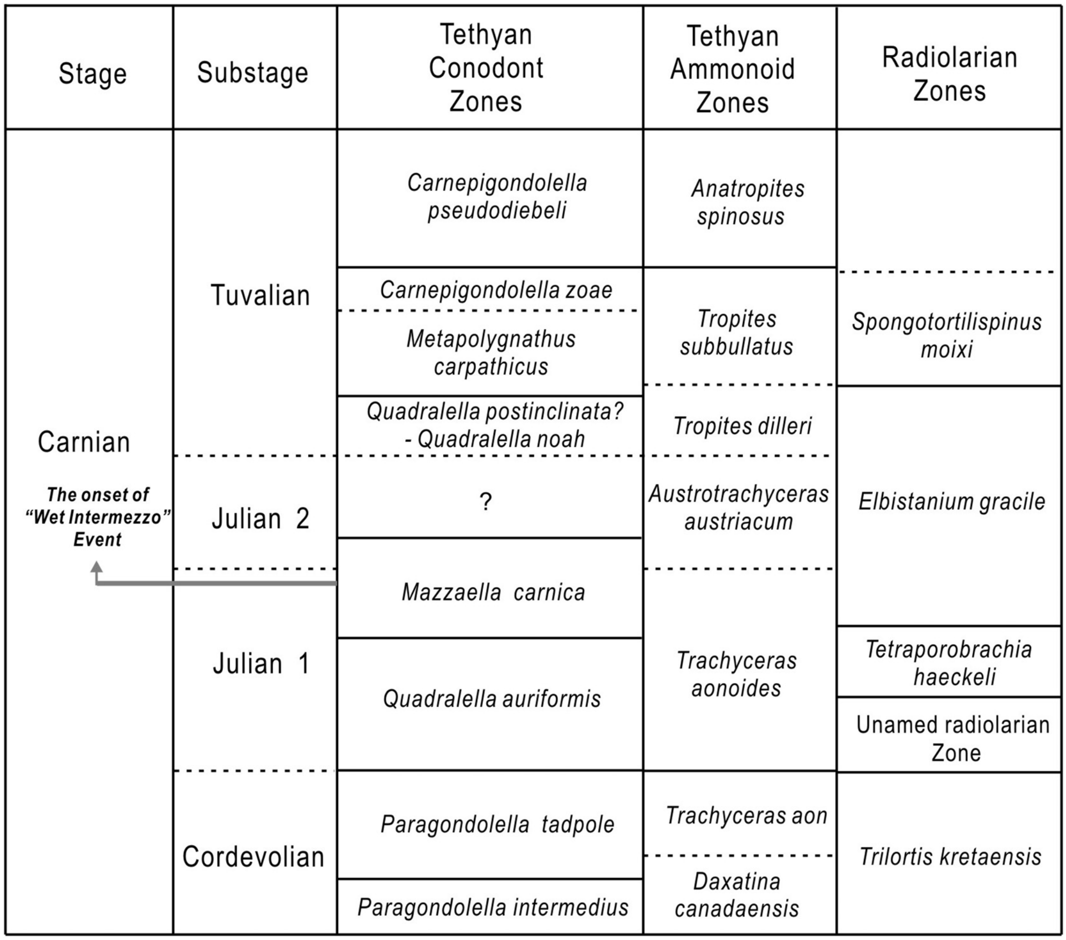

Fig. 1. Carnian biostratigraphy correlation among conodont, ammonoid and radiolarian zones and approximate onset of the Carnian Pluvial Episode. The conodont zones are modified after Kozur (2003a), Hornung et al. (2007a), Orchard (2010) and this study. Ammonoid zones is after Ogg et al. (2016), which was based on Jenks et al. (2015). Tethyan radiolarian zones are from Kozur (2003) and Nakada et al. (2014). The "Cordevolian" substage of Early Carnian that equates to *D. canadensis* and *T. aon* ammonoid zones (e.g., Kozur and Bachmann, 2010) is often combined with the Julian substage, so that an enhanced Julian substage spans the entire Early Carnian. Rigo et al. (2018) proposed an alternative set of Carnian conodont zones; which merged *P. intermedius* through *Q. auriformis* into a single *Q.* (*or Paragondolella*) *polygnathiformis* Zone, termed the unnamed one following *Ma. carnica* as the *Paragondolella praelindae* Zone after the interpreted first occurrence of the index taxa in mid-Julian 2 sub-stage, and replaced the basal Tuvalian *Q. postinclinata*?-*Q. noah* with a *Carnepigondolella*, *tuvalica* Zone, etc.

Previous biostratigraphic research has mainly focused on the West Tethys region. Hornung et al. (2007a) reported the Rheingraben Event at the Rappoltstein (Berchtesgaden, southern Germany). According to the ammonoids and conodonts, the Rheingraben event was interpreted to have its onset within the *Trachyceras aonoides* ammonoid zone and near the base of the *Metapolygnathus carnicus* (=*Mazzaella carnica*) conodont range zone, which were correlated to an age of late Early Carnian.

Kozur and Bachmann (2010) studied the Carnian Pluvial Episode of the Stuttgart Formation of the Germanic Basin and correlated its onset to the upper part of the *Austrotrachyceras austriacum* ammonoid zone of upper Julian. However, there is a widespread hiatus below the Stuttgart Formation, which may have removed the lower part of *Austrotrachyceras austriacum* ammonoid zone and the underlying *Trachyceras aonoides* ammonoid zone. Major negative shifts of carbon isotopes recorded in the Dolomites (Italy), Lunz (Austria) and Balatonfüred (Hungary) occur within the *Austrotrachyceras austriacum* ammonoid zone and are suggested to be coeval with the main episode of the Carnian Pluvial Event (e.g., Dal Corso et al., 2015). In the East Tethys region, at the Guling 2 section of Spiti (Indian Himalaya), a sudden increase of terrigenous influx is dated as uppermost *Trachyceras aonoides* ammonoid zone (Hornung et al., 2007b). In the Japanese record of the pelagic realm of Panthalassa, a wet climatic episode has been interpreted on the basis of analyses of aeolian dust influx from Asia to be within the radiolarian *Elbistanium gracile* Zone (Nakada et al., 2014) (Fig. 1). Therefore, according the correlation between ammonoid zones and conodont zones, the onset of the Carnian Pluvial Episode appears to be in the upper part of *Trachyceras aonoides* ammonoid zone (Fig. 1).

We obtained detailed conodonts results from the Guanyinya and Qingyangou sections near Hanwang Town of Sichuan Province in South China. These conodont assemblages allowed us to clarify the timing of the facies change that has been proposed as a regional record of the Carnian Pluvial Episode in this part of the East Tethys and to improve the correlation of conodont events between the western and the eastern Tethys regions.

2. Geological setting

The Guanyinya and Qingyangou sections are situated on two limbs of same syncline about 5 km northwest of Hanwang Town, Mianzhu City district, Sichuan Province, South China (Fig. 2). The lithology of these sections is detailed in Shi et al. (2017) and Jin et al. (2018). The uppermost portion of the Middle Triassic Tianjingshan Formation is a laminar dolomite (Fig. 3). The lower part of the Upper Triassic Maantang Formation (correlated to Unit 1 of Shi et al., 2017) is dominated by oolitic limestone and bioclastic limestone. The middle Maantang Formation (correlated to Unit 2 of Shi et al., 2017) is dominated by bioclastic limestone, thrombotilic limestone and sponge mound with shale.

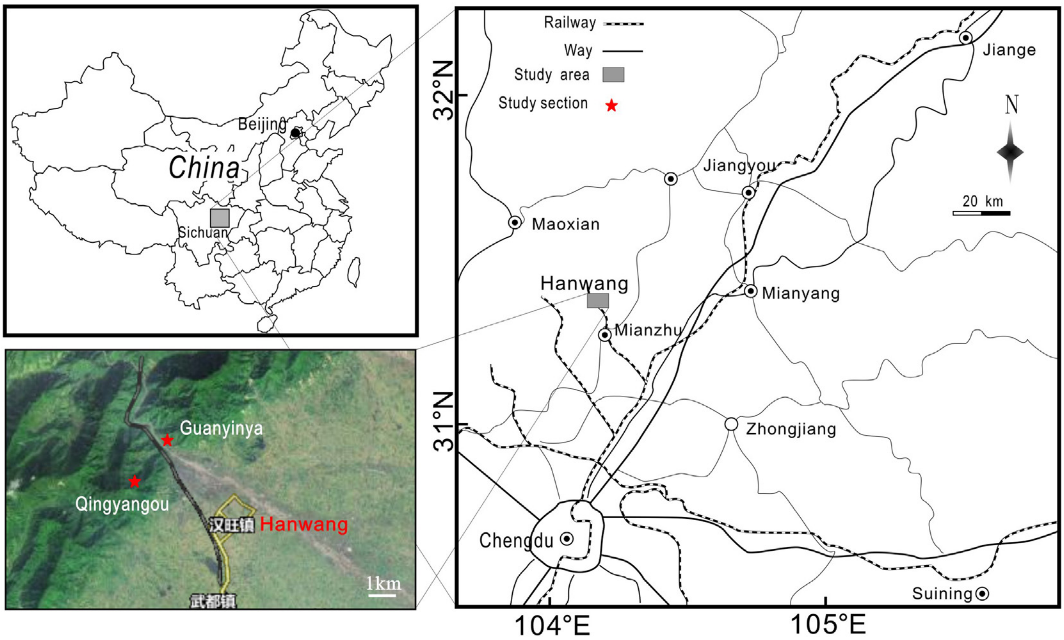

Fig. 2. Location of the studied sections northwest of Hanwang Town, Sichuan Province, China. Guanyinya section GPS position: N31°28′23.43″, E104°08′47.37″; Qingyangou section GPS: N31°27′29.42″, E104°09′04.25″.

The upper Maantang Formation (correlated to Units 3–4 of Shi et al., 2017) is dominated by shale and muddy siltstone (Fig. 3).

Some ammonoids, conodonts and plants have been reported in these sections (Shi et al., 2017). The Qingyangou section has a magnetostratigraphy (Zhang et al., 2015) (Fig. 3), but the assignment of these polarity zones to other reference magnetic polarity scales for the Carnian depends on the identification of the biostratigraphy and interpretation of hiatuses within and between units.

3. Materials and methods

Quartz grain and oolite contents were statistically analyzed from thin sections of the limestones in Bed 2 through Bed 17 of the Guanyinya section (Fig. 3). The frequency analysis used counts of > 300 points per thin section after applying Photoshop software to create an appropriate grid for point counting. In this method, grains or matrix material that fall directly under the cross point are identified and recorded in an excel file. A greater number of counted and identified points will yield more adequate and precise results, and 300 counts were considered to provide sufficient accuracy for the frequency of components (Flügel, 2004; Payne et al., 2006).

Samples (each weighing > 5 kg) for obtaining conodonts were collected from the Guanyinya section (53 samples) and the Qingyangou section (13 samples). After dissolving in 10% acetic acid, the residues of these samples were separated using the LST heavy liquid method (Yuan et al., 2015) for collecting conodonts. A total of 627 conodonts are obtained from the 53 conodont samples of the Guanyinya section. Among them, 312 specimens were identified as belonging to the genera *Quadralella*, *Budurovignathus*, *Parapetella* and *Mazzaella*. A total of 87 conodonts were obtained from the 13 conodont samples of the Qingyangou section. Among them, 49 specimens were identified as belonging to the genera *Quadralella*, *Parapetella* and *Mazzaella* (Table S1 of Supplemental material). Most of the conodonts were photographed using a scanning electron microscope (SEM) at the State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences (Wuhan) and typical specimens are shown in Figs. S1, S2 and S3 of the Supplemental material.

4. Results

4.1. Revised lithostratigraphic assignment of the onset of the Mid-Carnian "West Intermezzo" at Hanwang

Previously, Shi et al. (2017) compared the Carnian Pluvial Phase in western Tethys realm and the facies changes in Sichuan to suggest that the onset of the Carnian Pluvial Episode in the western Sichuan Basin was at the karst surface on the top of Bed 12 (one bed up within Unit 2) at Guanyinya or on the top of Bed 3 at Qingyangou, followed by a distinctive input of clay-rich siliciclastic sediments with plant debris and the drowning of the regional carbonate platform. Our analysis of the quartz contents from the Guanyinya support this general interpretation, but we propose that the important lithologic change is at the base of Bed 12 (base of Unit 2), rather than at its top – and this has important implications for the biostratigraphic age correlation. Quartz is a highly weather resistance mineral, commonly associated with terrigenous input. Here particle-counting of them is based on two reasons in this study: 1) the quartz particle is recognizable under microscope, and feasible to count; 2) it is terrigenous in origin, rather than diagenetic, based on texture observation, e.g., roundness. Diagenetic microquartz is common in limestones, but it is not the case here, because even silicification did not appear in the limestone concerned.

The quartz contents from the thrombolitic limestone and the sponge mound (Beds 14 and 15) are significantly greater than within the underlying limestones (Fig. 3). However, Bed 12 already shows a minor amount of quartz input, suggesting an initial precursor to the later major terrigenous influx.

The pattern of carbonate ooids analyzed in this study also implies that the initial onset of this event probably happened below the horizon that had been suggested by Shi et al. (2017). Carbonate ooids are non-skeletal grains that are common in some modern carbonate deposits of shallow marine environments, such as the Bahamas (Reeder and Rankey, 2008), Persian Gulf (Purser, 1973), Yucatan Peninsula (Ward and Brady, 1973) and Shark Bay of Australia (Reid et al., 2003). Their paleoclimatic and paleoceanographic implications were explored by Lees (1975), who compiled the available data on modern marine carbonate ooids with ambient salinity and temperature. This led to the conclusion that the modern carbonate ooids form mainly in subtropical

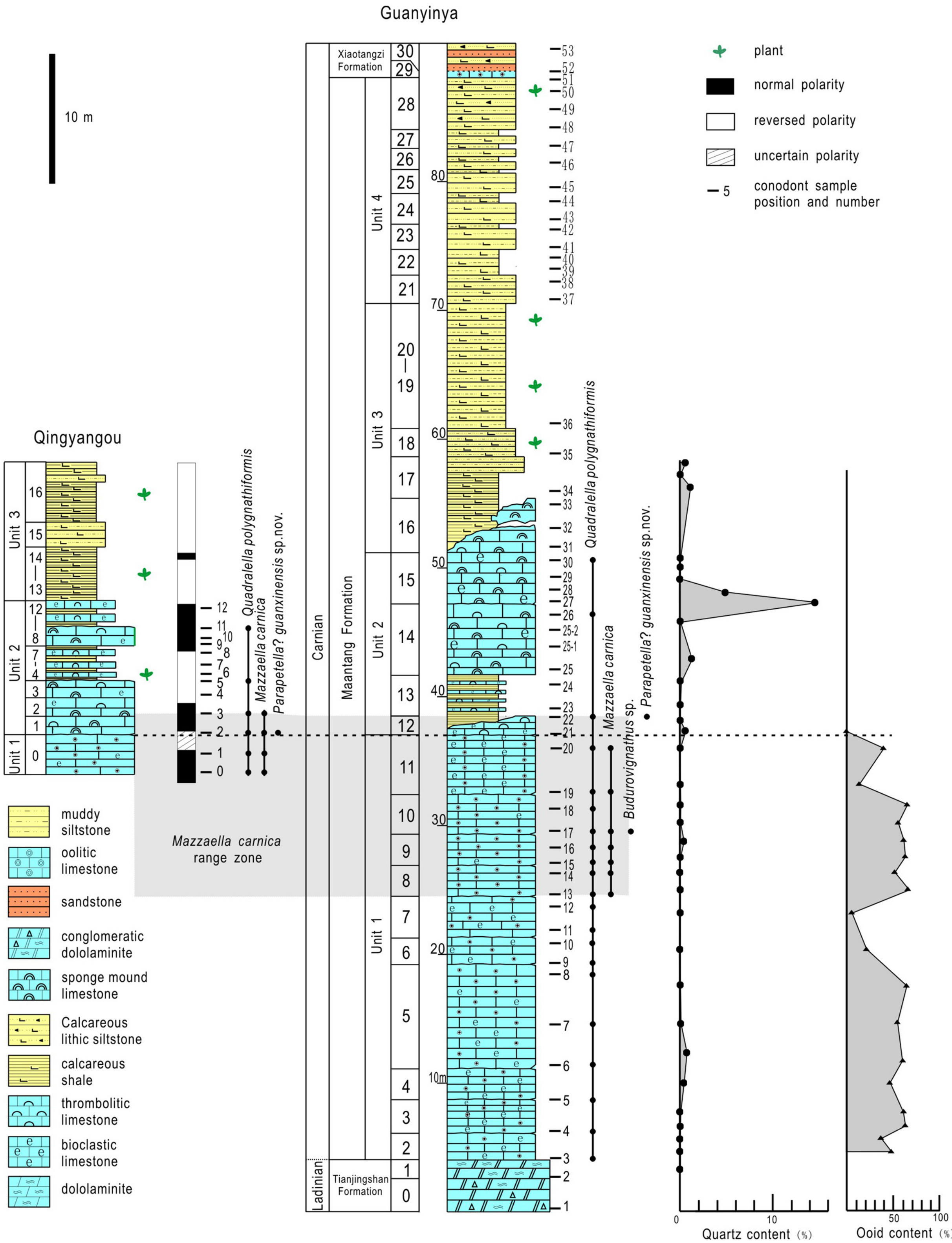

Fig. 3. Conodont distributions and quartz and oolite contents from the Maantang Formation of the Hanwang sections. Lithologic columns are after Shi et al. (2017); and the magnetostratigraphy is from Zhang et al. (2015). The dashed line is the interpreted re-assignment of the onset of the Carnian Pluvial Episode in these Sichuan sections.

environments with a consistent elevated salinity. A similar trend for the distribution of Paleozoic oolites was identified by Witzke (1990), who delineating the relevant paleoclimatic zones with lithic indicators that included oolites. An association of oolites with more arid climates is guaranteed when the carbonate ooids are associated with evaporates.

Carbonate ooids are widespread in Lower and Middle Triassic successions in South China and eastern Tethys (e.g., Li et al., 2015). Evaporites of Early Triassic age are also widely distributed in South China

(e.g., Liu and Xu, 1994). Therefore, we suggest that when oolites are abundant within the Middle Triassic and lower Carnian facies in our Sichuan sections, then this association implies a relatively arid climate in that basin.

The limestones of Unit 1 of the Maantang Formation at Hanwang are rich in oolites (Fig. 3) and therefore are interpreted to have been deposited during an arid climate (Ji et al., 2016). However, the oolites are no longer present above the base of Unit 2. This can be regarded as the local cessation of the long-term arid climate that was predominant since the base of the Triassic. Although carbonate sedimentation still continued as the thrombolitic limestone bed above this boundary between Unit 1 and Unit 2 (Shi et al., 2017), we follow Hornung et al. (2007a) to suggest that this was a local equivalent to 'autochthonous carbonate formation as thrombolite crusts' during the 'Rheingraben event'.

Based on these observations of quartz and oolite contents, here we re-assign the onset of the Carnian Pluvial Episode at Hanwang to the boundary between Unit 1 and Unit 2 of Maantang Formation (Fig. 3).

4.2. Revised conodont stratigraphy

The occurrence of conodont *Quadralella polygnathiformis* from Unit 1 and the lower part of the Unit 2 at the sections of Hanwang (Shi et al., 2017) implied a Carnian age, but that taxon has a long range. In this study, in addition to the occurrence of *Quadralella polygnathiformis*, *Budurovignathus* sp., we obtained many specimens of *Mazzaella carnica* and two specimens of a new species, *Parapetella*? *guanyinensis* sp. nov. (Table S1 of Supplemental material).

Genus *Budurovignathus* spans from Ladian to Julian, and genus *Mazzaella* spans only a very brief time interval around the Julian 1–2 boundary (Chen et al., 2015). The base of the *Metapolygnathus carnicus* (= *Mazzaella carnica*) range zone reported at the Rappoltstein (Berchtesgaden, southern Germany) was considered to coincide with the onset of the Rheingraben Event (Hornung et al., 2007a), although the occurrence data was very sparse.

The conodont *Mazzaella carnica* range zone is identified from Beds 8–12 at the Guanyinya section and from Beds 0–2 (but begins possibility below) in the Qingyangou section (Fig. 3). However, compared to the very sparse horizons with *Mazzaella carnica* at the Rappoltstein, there are numerous horizons at the Qingyangou and Guanyinya sections. The onset of the Carnian Pluvial Episode, as we assigned it in these sections based on the patterns of quartz and oolite abundances, does not coincide with the lower limit of the *Mazzaella carnica* range zone, but begins within it. Interestingly, the first occurrence of *Parapetella*? *guanyinensis* sp. nov. is very close to the horizon of the assigned onset of the Carnian Pluvial Episode at these two sections (Fig. 3).

The taxonomic details, detailed range data and sets of images for the two conodonts with biostratigraphic significance for the Carnian Pluvial Episode, and discussions of similar-looking taxa are provided in the Supplemental material.

5. Discussion

5.1. Carnian conodont biostratigraphy correlation between West and East Tethys

Agreement on taxonomy, hence identification, of Carnian conodonts in some lineages is elusive; and it is possible that the ranges of taxa in different regions is affected both by paleogeography and by the simple fact that some workers have different opinions on the separation of species within a genus lineage. In particular, it seems difficult to agree on identifications within the "*polygnathiformis*" lineage within the broad Paragondolellinae family. There are only subtle differences among *Q. polygnathiformis*, *Q. noah* and *Q. praelindae*, and the natural variability within the long-ranging *Q. polygnathiformis* can lead some workers to assign some specimens of *Q. polygnathiformis* within the Julian substage to the *Q. noah* and *Q. praelindae* taxa, even if these are not really the "true" *Q. noah* and *Q. praelindae* taxa that are reportly limited to the late Julian (*Q. prealindae*) or earliest to mid-Tuvalian (*Q. noah*) according to Rigo et al. (2018).

Standardization of Carnian conodont nomenclature and zonal biostratigraphy of South China, indeed for other regions of the globe, is still in flux. Previously, Yang et al. (1995) identified a *Neogondolella* (= *Quadralella*) *polygnathiformis*- *Neogondolella maantangensis* assemblage zone, a *Neogondolella* (= *Quadralella*) *polygnathiformis*- *Neogondolella tadpole* assemblage zone and a *Neogondolella polygnathiformis* Zone in Carnian platform sections of Guizhou, South China, that were assigned to the Cordevolian, the Julian, and the lower part of Tuvalian substages, respectively. Subsequently, Yang et al. (1999) proposed a *Budurovignathus diebli*- *Pseudofurnishius* sp. A assemblage zone, a *Paragondolella* (= *Quadralella*) *polygnathiformis* Zone and an *Epigondolella nodosa* Zone in basinal Carnian sections of South China, that might correspond respectively to the Coedevolian, the Julian to the lower part of Tuvalian, and the upper part of Tuvalian substages. Globally, Kozur (2003) summarized five conodont zones in Tethydis and Western Pacific regions; in ascending order they are: *Budorovignathus diebli*- *Paragondolella polygnathiformis* assemblage zone of Cordevolian, *Gladigondolella tethysis*- *Paragondolella polygnathiformis* assemblage zone of Julian, *P. postinclinata*- *P. polygnathiformis* assemblage zone, *Paragondolella carpathica* Zone and *Epigondolella nodosa* Zone of Tuvalian. He also proposed four conodont zones in North America; in ascending order they are: *Paragondolella polygnathiformis* Zone from Cordevolian to Julian, *Epigondolella nodosa* Zone, *Metapolygnathus "communisti"* Zone and the lower part of *Epigondolella primitia s.l.* zone of Tuvalian. Chen et al. (2015) listed a set of revised Carnian conodont zones in North America after Orchard (2007) and (Orchard, 2014); in an ascending order as follows: *Paragondolella intermedius* Zone of the lower part of Cordevolian; *Paragondolella tadpole* Zone of the upper part of Cordevolian and Julian; and three Tuvalian zones: *Quadralella polygnathiformis* Zone, *Carnepigondolella samueli* Zone (including four subzones: *Carnepigondolella eozoae-K. ludingtonensis* Subzone, *Carnepigondolella zoae* Subzone, *Carnepigondolella medioconstricta* Subzone, *Carnepigondolella spenceri* Subzone), *Primatella primitia* Zone (including four subzones: *Acuminatella sagittale-Parapetella beattyi* Subzone, *Acuminatella angusta-Metapolygnathus dylani* Subzone, *Acuminatella acuminata-Parapetella prominens* Subzone, *Metapolygnathus parvus* Subzone).

This lack of standardization of Cordevolian-Julian conodonts biostratigraphy inhibits correlation among regions and previous studies. The *mostleri-tadpole*, *auriformis* and *carnicus*, conodont biozones are present at the Rappoltstein of Berchtesgaden, southern Germany during this interval (Hornung et al., 2007a), and we refer to this conodont biostratigraphic frame (Fig. 1) for correlation of Cordevolian and Julian substages of the Lower Carnian.

5.2. The onset of the Carnian Pluvial Episode

Biostratigraphy is a useful method to define the onset of the Carnian Pluvial Episode. Hornung et al. (2007a) reported the *Metapolygnathus auriformis* (= *Quadralella auriformis*) and *Metapolygnathus auriformis* interval zone (below the *Metapolygnathus carnicus* range zone) at the Rappoltstein (Berchtesgaden, southern Germany) and assigned this onset in the upper part of *Trachyceras aonoides* ammonoid zone, and at the base of *Mazzaella carnica* conodont interval zone, correlated to an age of uppermost of Julian 1 (Fig. 4).

Even though the absence of *Quadralella auriformis* in our collection precludes us in assigning this *auriformis* zone in our Sichuan sections, the interpreted horizon of the initial onset of the Carnian Pluvial Episode is within the conodont *Mazzaella carnica* range zone (Fig. 1) and very close to the first occurrence of *Parapetella*? *guanyinensis* sp. nov. at Hanwang.

The onset of the Carnian Pluvial Episode is within a normal-

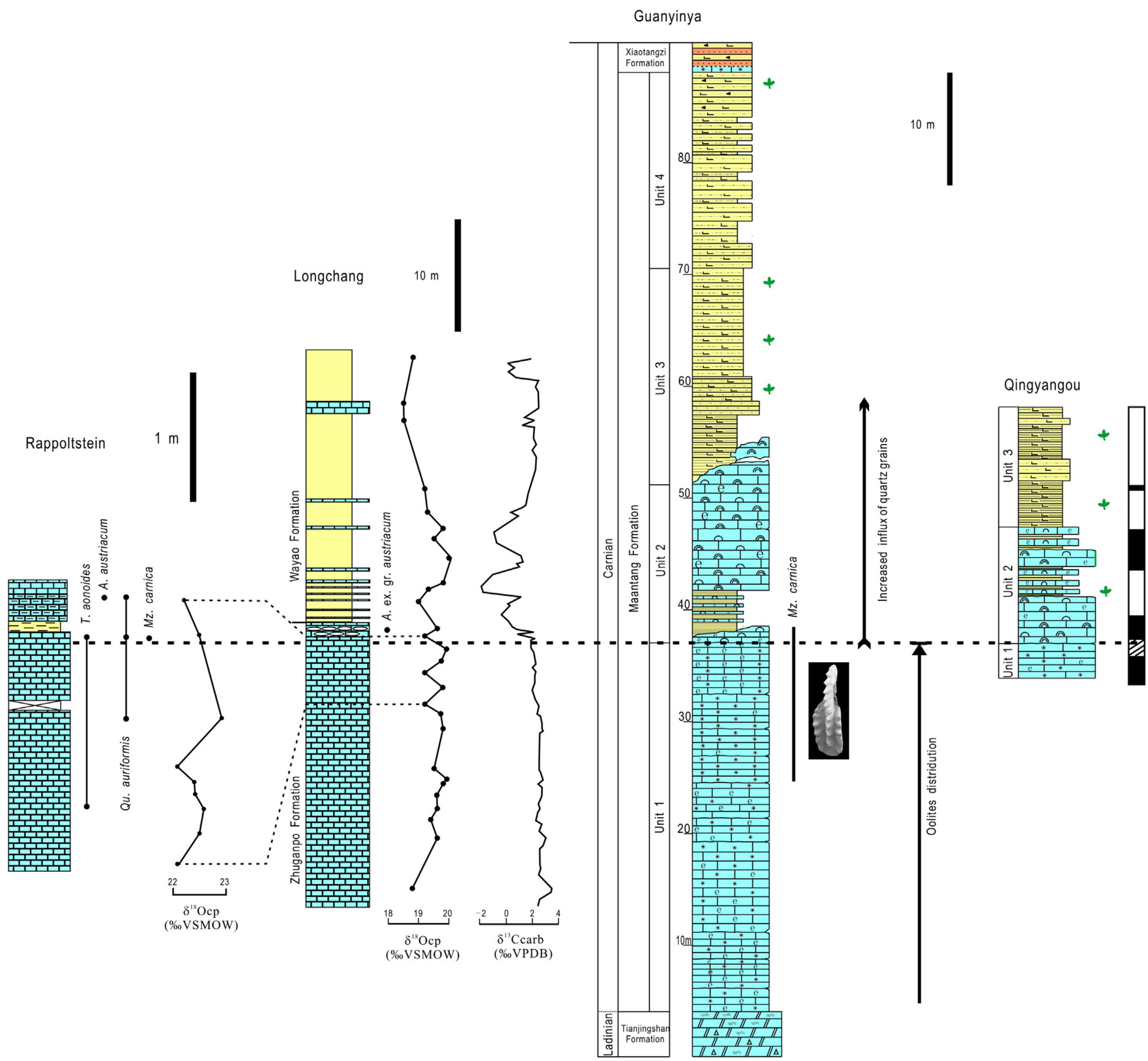

Fig. 4. Correlation of the onset of the Carnian Pluvial Episode among different regions. Data of Rappoltstein (southern Germany) are from Hornung et al. (2007a); data of Longchang (Guizhou Province, South China) are from Sun et al. (2016). See Fig. 3 for key to lithological symbols.

polarity-dominated zone in the Qingyangou section (Zhang et al., 2015); and perhaps a future downward extension of that magnetostratigraphy and verification in the nearby Guanyinya section may enable characterization of the brief *Mazzaella carnica* range zone to aid in global high-resolution correlation to different facies. The dominance of reversed-polarity within the lower Stuttgart Formation (which is the first half of "Carnian Pluvial Episode" in the Germanic Basin) has same polarity signature as the Reversed-polarity onset and lowermost portion of the clay/clastic Wayao Formation of South China (Zhang et al., 2015), which was considered to be the equivalent of the Carnian Pluvial Event (e.g., Sun et al., 2016). While this reversed-polarity dominance does not prove equivalency by itself, it remains to be demonstrated how to correlate the polarity pattern of this Sichuan interval to the mid-Tuvalian substage, which seems to be apparently dominated by normal-polarity. Another independent publication that incorporated this same section (Jin et al., 2018) did not include the magnetostratigraphy column. Obviously, more studies of magnetostratigraphy of multiple sections with less ambiguous biostratigraphic assignments based solely on conodonts are required.

At present, the composite mid-Carnian magnetostratigraphy from the Germanic Basin (Zhang and Ogg, in Dal Corso et al., 2018) suggests that the Qingyangou sampling may only represent the lower half of the complete Carnian Pluvial Episode.

The Longchang section in Guizhou Province of South China is reference section with a negative carbon-isotope excursion just above the termination of the limestone facies (Sun et al., 2016) that has been suggested to correlate with similar negative excursion recorded at the termination of the shallow-water platform of the Dolomites (Dal Corso et al., 2012, 2015). The Longchang section lacks both *Quadralella auriformis* and *Mazzaella carnica* conodonts, but there has been a finding of the ammonoid *Austrotrachyceras* ex gr. *A. austriacum* in the uppermost part of Zhuganpo Formation limestones. Therefore, Sun et al. (2016) interpreted a correlation to the Carnian Humid Episode with its onset within a conodont *Paragondolella foliata*-*Quadralella polygnathiformis*

assemblage zone and near the top of Julian 1 age, just below the occurrence of *Austrotrachyceras* ex gr. *A. austriacum* (see Fig. 4 in Sun et al., 2016), which is coeval with the onset of the Rheingraben Event in southern Germany (Fig. 4).

In summary, according the biostratigraphic correlation among Rappoltstein, Longchang and Hanwang sections, the onsets of the Carnian Pluvial Episode occurred at these places are synchronous (Fig. 4). Notably, influx of large amounts of siliciclastics (e.g. shales) transported from terrestrial weathering and increased fluvial activity produced by this wet climate is a distinguishing characteristic of the interval. Tectonic movement (compression and uplift) in foreland basins of course can increase the input of terrigenous detritus into the basins. However, the time scale for tectonic movement is usually gradual over a long period with a Myr-scale, which is reflected in large cycles and large progressive changes. Definitely this played a role in the long-term change of Sichuan Basin into a non-marine setting during the Norian. In the longer time frame, the tectonic compression influenced the terrigenous supply in the study region by the eventual termination of the carbonate factories, and then the major > 1000-m thick greywacke–like succession that overlies our studied interval. But our data is partly using the rather sudden influx (significant, but subtle) of quartz grains and other clastics into a still-relatively carbonate-dominated shelf, which we consider to be a signature of increased direct surface runoff, hence a climatic shift to a more "pluvial" phase.

The climate at the West Tethys changed again to arid at the approximate base of the Tuvalian substage (Kozur and Bachmann, 2010); therefore, this Carnian Pluvial Episode may span only from the top of Julian 1 to the base of Tuvalian in the western Tethys. However, there was not a corresponding return to significant arid conditions in China. Beginning from this onset of the Carnian Pluvial Episode, coal-bearing depositions are widespread in both South and North China (e.g., Liu and Quan, 1996). During the Late Triassic, the plant fossils *Danaeopsis-Bernoullia* Assemblage indicates that the North China remained as a temperate-moist climate; and the *Dictyophyllum-Clathropteris* Assemblage indicates a humid-warm climate continued in South China (Chen and Cao, 1986). This implies that this wet climate started from the late Julian in East Tethys is not "Pluvial Episode" in this region, but the opening chords of a new humid realm.

A negative shift of organic carbon isotopes during this Carnian Pluvial Episode has been recorded in the West Tethys with a suggested linkage to the eruption of Wrangellia flood basalts (Dal Corso et al., 2012, 2015). An apparent coeval negative shift interval of carbon isotopes of carbonate during this Carnian Pluvial Episode were reported at Longchang of Guizhou, although there was no indication of a significant temperature trend in the seawater based on the oxygen isotopes from conodont apatite (Fig. 4 in Sun et al., 2016; and Fig. 4 in our study).

6. Conclusions

The rapid transition between limestones into terrigenous clastic deposition in Sichuan and throughout the Yangtze Platform region of South China has been interpreted as a regional impact of the Carnian Pluvial Episode of the West Tethys, but high-resolution correlations have been difficult. We reexamined two reference sections in the Maantang Formation at Hanwang in Sichuan Province to resolve the stages in the facies transition and to improve the biostratigraphic age constraints. There is an onset of significant quartz content into the limestone of Beds 14–15 followed by the absence of oolites above the Bed 12 at the base of Unit 2 of Maantang Formation. These lithologic changes are interpreted as the initial onset of a more humid climate that terminated of the long-term arid climate of the Early and Middle Triassic of this part of South China. This horizon is within the conodont *Mazzaella carnica* range zone of the upper Julian substage of the lower Carnian. Therefore, the conodont markers imply that this level is coeval with the onset of the mid-Carnian " Rheingraben Event" at the Rappoltstein reference section in southern Germany. Therefore, the boundary between Unit 1 and Unit 2 of Maantang Formation is interpreted as the regional onset of the global Carnian Pluvial Episode. This correlation is supported by ammonoids in that Rappoltstein section which enable correlation with the beginning of the negative carbon-isotope excursion that coincides with the termination of the Yangtze Platform at the Longchang reference section in Guizhou, South China. This placement of the onset of the Carnian Pluvial Episode is very close to the first occurrence of *Parapetella*? *guanyinensis* sp. nov. at these Hanwang sections and the cessation of widespread shallow-water carbonate facies in South China. In contrast to West Tethys where arid conditions resumed after this Mid-Carnian episode, the climate of China in the East Tethys continued to be humid through the remainder of the Triassic.

Author contributions

HJ designed this study. HJ and JLY performed the conodont analyses. YC performed the quartz grain and oolite contents analysis. JXY interpreted the climate. HJ, JLY collected the samples. The manuscript was written by HJ, JO, JXY, YC and JLY.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (41830320, 41572324, 41472087), Special Project on Basic work of science and technology from Ministry of Science and Technology of the People's Republic of China (Sub-project, 2015FY310100-11) and the China Geological Survey (DD20160120-04). J. Ogg acknowledges the Overseas Distinguished Teacher Program of the Ministry of Education (MS2013ZGDZ[WH]028) for his visiting research professorship at the State Key Laboratory of Geobiology and Environmental Geology (CUG-Wuhan) and at the Chengdu University of Technology. We thank Prof. Yin Hongfu for his useful suggestions for this study, and Prof. Zhiqiang Shi, Xin Jin and Dacheng Wang for their help with fieldwork. All SEM pictures taken at the State Key Laboratory of Biogeology and Environmental Geology (China). We thank the taxa suggestion from Leo Krystyn and Michael Orchard. Manual Rigo, who highlighted potential similar-looking conodont taxa and potential alternate age assignments, and two anonymous reviewers are thanked for their useful comments during the review stage.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.palaeo.2019.02.004.

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